

LOW FREQUENCY

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Impedance Standards and Measurement Techniques
Generation and Measurement of Precise Signals

These two projects were combined as "Waveform Synthesis and Impedance Metrology" listed above.

AC-DC Difference Standards and Measurement Techniques

Project Leader:	Joseph R. Kinard
Staff:	2.0 Professionals, 1.0 Technician
Funding level:	\$0.6 M
Funding sources:	NIST (50%), Other Government Agencies (17%), Other (33%)
Objective:	Provide U.S. industry with the link between the direct voltage and current standards and alternating quantities by maintaining and improving the U.S. national standards of ac-dc difference, and the working standards, measurement systems, and techniques needed to provide viable calibrations and measurement services for thermal converters and shunts.

Background: Nearly all measurements of electric power, energy, alternating voltage and alternating current are traceable to the volt and ohm (dc quantities) through thermal transfer standards. Modern electronics makes possible digital instruments which can produce and measure alternating voltage and current parameters with precision and stability rivalling those of the best direct voltage and current standards. Improved NIST thermal transfer standards are needed to support the development, testing, production, and maintenance of such instruments. Thermal transfer standards are used to measure a quantity called "ac-dc difference," where ac, literally "alternating current," refers to the time varying signals and dc literally "direct current," refers to time invariant signals. NIST has developed new standards, nearly as good as existing national standards, based on semiconductor and thin-film processing technologies that are about to be commercialized and hence widely available. Present NIST standards are inadequate to calibrate these devices over their full range of capability. Moreover, manufacturers are introducing high-output current amplifiers and improved high-voltage resistors. An extension of the parameter space and improved accuracies of NIST calibration services are required to support these developments.

Work is underway to develop new primary, thermal transfer standards operating at cryogenic temperatures and with sensitivity approaching the quantum limit. This effort builds on the experience gained in the development of film multijunction thermal converters and on the design and application of extremely sensitive cryogenic thermometers. The new standards are expected to reduce uncertainties from the present lowest value of 0.8 microvolts per volt to 5 microvolts per volt to <0.1 microvolts per volt to 1 microvolt per volt. A new investigation of bootstrapping techniques to support high-voltage and current measurements is also being performed. This will be based on earlier, pioneering NIST work in this field and is expected to result, not only in improved NIST services, but in better, more efficient techniques for industrial standards maintenance as well. The U.S. has the largest manufacturing industry for thermal transfer instrumentation. NIST continues to provide support for this U.S. industry through an expanded ac-dc difference calibration service, CRADAs, and international comparisons and cooperations.

Current Tasks:

1. Maintain the primary, reference, and working sets of thermal transfer standards for ac-dc difference; provide and improve the ac-dc difference calibration service for voltage from 0.1 volt to 1000 volts at 2 hertz to 1 megahertz; and for current from 1 milliamperes to 20 amperes at 2 hertz to 100 kilohertz

FY 1986	Studied multijunction thermal converters and established them as the NIST primary standards of ac-dc difference for alternating voltage and current.
FY 1988	Recharacterized thermal voltage converters and reduced uncertainties in the frequency range 0.1 megahertz - 100 megahertz.
FY 1994	Studied the voltage dependence of thermal converters in the 200 volt - 1000 volt range and recharacterized the NIST high-voltage standards.
FY 1995	Studied and recharacterized thermal converter standards at 10 hertz to permit reduction in calibration uncertainties; Provided new ac-dc difference reference values from 10 kilohertz up to 30 megahertz to maintain consistency between this activity and NIST's higher frequency ac-dc difference calibration service.
FY 1996	Fabricated and tested new high-current, multi-converter module to replace damaged traditional converters; Published results; Fabricated and tested high-voltage, binary divider to confirm scaling of 200 volt to 1000 volt ranges (recent international comparisons revealed significant variations between national laboratories at these voltages); Prepared documentation for extending transfer shunt calibrations up to 100 kilohertz.
FY 1997	Complete and publish total reassessment of ac-dc difference calibration service uncertainties with a view to significant reductions; Publish documentation for extension of transfer shunt calibration down to 10 Hz.
FY 1998	Upgrade automated comparator systems to provide unassisted data analysis and interface with Electricity Division Calibration Service Database; Establish thin-film multijunction thermal converters as working standards; Remodel and improve ac-dc calibration laboratory physical plant.

2. Develop new thin-film converter technology and assist with the transfer of this technology to industry

FY 1989	Designed structure and photomasks for prototype thin-film multijunction thermal converters.
FY 1990	Perfected stress-balanced, multilayer membrane required for thin-film converter fabrication.
FY 1991	Mounted and tested completed chips.
FY 1992	Developed improved bonding pads for thin-film converters to greatly reduce errors as current converters; Patent granted February 1995; Cooperative program with industrial partner directed to the development and production of thin-film multijunction thermal converters.
FY 1993	Designed and produced integrated micropotentiometers which combined high performance multijunction converter and thin-film output resistors on the same chip; Patent granted February 1994.
FY 1995	Solved a remaining problem with wafer cleaning and metal to metal contacts, and continued successful production of converter chips; Fabricate additional converter chips, mount, and characterize as working standards; Provide chips to DoD and Sandia laboratories as per agreements.

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| FY 1996 | Characterized thin-film converters at various voltages, currents, and frequencies at room and cryogenic temperatures and began study to incorporate these devices as reference and working standards; Constructed and tested new thin-film thermal converter chips for currents above 0.5 A; Presented invited summary paper at CPEM 96 on thin-film converters. |
| FY 1997 | Develop and publish description of broadband mounting substrate to permit extension of integrated micropotentiometer frequency range; Study use of these devices as reference and working standards. |
| FY 1998 | Develop and test vacuum mountings and new longer time-constant versions of film multijunction converters; Design and fabricate improved high-current converters. |
3. Develop new low-temperature thermal converter standards and study fundamental limitations on the thermal transfer process
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| FY 1993 | Developed preliminary design for low-temperature primary standard converters based on superconducting kinetic inductance thermometer sensor. |
| FY 1994 | Began equipment procurement; Performed preliminary, low-temperature ac-dc difference measurements on thin-film multijunction thermal converters. |
| FY 1995 | Began study of low-temperature converter design using alternative superconducting transition edge device as sensor; Transition edge device appears more conducive to fabrication and incorporation into converter than kinetic inductor as originally planned. |
| FY 1996 | Assembled cryogenic system, made prototype converter chips using transition edge thermometers; Began initial testing of new low-temperature devices. |
| FY 1997-99 | Develop suitable designs and geometries for low temperature standards and investigate fundamental limitations on the thermal transfer process; Confirm accuracy of new low-temperature converters and establish them as NIST primary standards, if appropriate; Characterize existing thin-film converter designs at cryogenic temperatures. |
4. Support the measurement of ac quantities through interaction with industry and other national laboratories
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| FY 1993 | Cooperative program with industrial partner directed to the improvement of single junction thermoelements; Second cooperative program directed to characterization of a new automated thermal transfer standard. |
| FY 1994 | New cooperative program with industry directed to the improvement of voltage coefficients and frequency compensation for their high voltage range resistors; Cooperative program with University of Maryland, Department of Materials and Nuclear Engineering, directed to utilization of thin-film multijunction thermal converters to measure properties of sputtered metals during deposition. |
| FY 1995 | Trained professional staff member and provided equipment and extensive calibrations to the Mexican national measurement laboratory, CENAM; Participated in an international comparison of a multijunction thermal converter travelling standard at the highest uncertainty level. |
| FY 1996-97 | Participated in international comparisons of high-frequency thermal converters with the laboratory responsible for their maintenance in Spain (INTA); Assisted various companies to develop improved thermal converter instrumentation. |

FY 1997-98 Assist laboratories of developing nations in the Americas to bring their capability up to international standards; Participate in international intercomparisons, including intercomparisons for high-voltage.

Waveform Acquisition Devices and Standards

Project Leaders: T. Michael Souders, Nicholas G. Paulter, Jr.

Staff: 4.0 Professionals, 0.9 Technician

Funding level: \$0.9 M

Funding sources: NIST (44%), Other Government Agencies (50%), Other (6%)

Objective: Develop standards, test methods, and analysis techniques for waveform acquisition devices. Expand and improve the present time domain waveform measurement services to support high performance samplers and digitizers, as well as fast pulse and impulse sources, operating over frequencies to 50 gigahertz.

Background: Manufacturers and users of time domain instrumentation need state-of-the-art methods and standards for characterizing the performance of increasingly sophisticated products. Waveform sampling has become a critical, pervasive technology in instrumentation and continual advances are being made. Data converter sales were \$1.1 billion in 1990, and sales of waveform recorders and analyzers reached \$718 million in 1991. This industry needs advances in standards, test methods and error analyses to facilitate continued growth. In turn, the computer, telecommunications and integrated circuit industries (each critically dependent on sampling technology) will all benefit. Improved optoelectronic technology will be needed for advancement and development of state-of-the-art electronic devices, semiconductor structures, and printed circuit board materials. NIST has pioneered many of the techniques and standards used today for testing and calibrating precision time domain instruments and systems. In response to new advances in devices and products, NIST will expand and improve the present time domain waveform measurement services to support high performance samplers and digitizers, as well as fast pulse and impulse sources, operating over frequencies up to 50 gigahertz. Specific goals include: (1) developing and applying accurate sampling comparator systems to measure the settling parameters of fast pulse generators, amplifiers, and digital-to-analog converters (as well as making accurate voltage measurements); (2) providing error analyses on the effects of non-idealities in sampling systems; (3) researching and developing optoelectronic devices and techniques for ultra-fast sampling and pulse generation applications and electric-field probing; and (4) supporting and contributing to consensus standards for specifying and testing waveform acquisition devices, and standards for pulse terminology and characterization.

Current Tasks:

1. Data converter/waveform recorder testing

FY 1989	Institute of Electrical and Electronic Engineers (IEEE) issued <i>Trial Use Standard for Digitizing Waveform Recorders</i> , developed under NIST leadership; Many NIST-developed test methods are included.
FY 1990	Studied effects of timing jitter in sampling systems; Award-winning paper published.

FY 1991	Characterized filters for analog-to-digital (A/D) converter test bed; Subcommittee on A/D converters formed under IEEE.
FY 1993	Developed reference pulse generator for use in pulse measurement intercomparison program (round-robin); Analyzed performance of least-squares sine wave curve fitting algorithms used in digital oscilloscope and A/D converter testing.
FY 1994	Began pulse measurement round-robin; Studied phase-plane compensation method to reduce dynamic nonlinearity errors in sampling channels; Presented paper on results.
FY 1995	Developed analysis of bounds on frequency response estimates derived from uncertain step response data and presented paper; Completed testbed hardware for characterizing high performance A/D converter (up to 14 bits, 1 gigahertz sample rate); Quantified the systematic and random uncertainties associated with the test method proposed in IEEE Standard 1057 for measuring time-base linearity errors.
FY 1996	Began development of a wideband oscilloscope calibration system in response to needs articulated by the Air Force.
FY 1997	Complete development of oscilloscope calibration system; Conclude first pulse measurement round-robin and publish results; Revisit phase-plane characterization of sampling channels.
FY 1998	Conclude phase plane analysis and publish results.
FY 1999	Complete development of the high performance A/D converter testbed; Incorporate test methods into IEEE Standard 1241.
2. Sampling comparator systems	
FY 1991	Completed design of custom integrated circuit comparator for sampling applications; Goals: 2.5 gigahertz bandwidth, elimination of "thermal tails" (settling to 0.1% in 2 ns).
FY 1992	Comparators fabricated at foundry and incorporated into sampling comparator system (SCS); Design goals met.
FY 1993	Developed ultra-flat response, ± 20 Volt attenuator for SCS.
FY 1994	Began development of wideband (10 hertz - 200 megahertz) sampling voltmeter.
FY 1995	Developed quasiequivalent-time time-base, probe control, and memory management circuits; Produced a working prototype voltmeter.
FY 1996	Completed signal-conditioning front end, second generation time-base, and time-base autocal circuits for sampling voltmeter, and presented paper on design, architecture, and error sources.
FY 1997	Complete and deliver wideband sampling voltmeter; Upgrade SCS using new time-base and control circuitry developed for voltmeter; Begin development of a triggerable-oscillator time-base; Carry out feasibility study for a 5 gigahertz bandwidth comparator for use in SCS.
FY 1998	Complete the design for the new comparator; Complete new time-base and install in SCS.
FY 1999	Fabricate and test new comparator; Incorporate into the SCS.
FY 2000	Offer 5 gigahertz bandwidth fast settling parameter calibration services.

3. Pulse measurement services

FY 1992	Fast pulse metrology program transferred from Boulder; Broadband pulse measurement services reestablished in Gaithersburg.
FY 1993	Began special measurement services for settling performance using SCS; Implemented "nose-to-nose" method for measuring the impulse response of high speed scopes; Developed improved gallium arsenide photoconductors for high-speed pulse generation.
FY 1994	Provided assessment of pulse energy measurements for inkjet print head industry (using SCS); Brought new, computer-based pulse measurement system on-line.
FY 1995	Trained new operator to perform the 65000 series of NIST Special Tests; Completed error analyses for Impulse Spectrum Amplitude, Baseband Pulse Parameters, and Pulse Delay Time tests.
FY 1996	Evaluated deconvolution algorithms and selected new algorithm for use in pulse parameter estimation software; Coded deconvolution and pulse parameter estimation algorithms in LabView software; Developed control and automation software to upgrade pulse parameter measurements; Performed pulse settling calibrations for 8 precision step generators and 3 high speed digital-to-analog converters, and pulse energy calibrations for 11 pulse generators.
FY 1997	Evaluate time-base linearity test methods, code the selected method in LabView, and develop an algorithm to correct for timing errors in sampled waveforms.
FY 1998	Provide uncertainty envelope calculations for entire measured waveform on point-by-point basis; Begin characterization of 50 gigahertz sampler.
FY 1999	Complete characterization of 50 gigahertz sampler and incorporate into broadband pulse measurement system; Offer 50 gigahertz bandwidth fast pulse calibration services.
FY 2000	Upgrade time delay and impulse spectrum amplitude measurement services.

4. Optoelectronic technology

FY 1992	Installed laser system and associated diagnostics; Designed photoconductors (for photoconductive pulse generator) and developed fabrication process.
FY 1993	Added pulse selector to laser system and started photoconductor performance tests; Designed and tested prototype photoconductor electrical package; Developed new broad-band electrooptic voltage measurement technique.
FY 1994	Improved performance of packaged photoconductor and reduced aberrations; Completed evaluation of electro-optic voltage measurement system; Found stability of system to be inadequate for precision pulse metrology work.
FY 1995	Investigated potential replacement laser systems; Ordered diode-laser system; Extended time-domain printed wiring board measurement technique to provide dielectric loss information.
FY 1996	Introduced optical delay/splitter to reduce laser jitter effects from 7 to 0.5 picoseconds.
FY 1997	Test diode-laser based system operation; Make improvements where needed; Test photoconductor performance using diode-laser system.
FY 1998	Determine impulse response of NIST's pulse calibration system using diode-laser based system.

FY 1999	Develop an optoelectronic-based, high temporal resolution (<1 ps) sampling system with 1% amplitude uncertainty; Characterize the diode-laser system pulse output waveform.
5.	Pulse Measurement Applications
FY 1996	Developed time-domain method to measure the dielectric constant of printed wiring board materials; The method uses inexpensive equipment and provides accuracy comparable to frequency domain techniques.
FY 1997	Investigate short and long term repeatability of the dielectric measurement technique.
6.	Terahertz Wave Imaging
FY 1997	Analyze candidate detection methods in terms of signal-to-noise level and response time for low level signals; Examine collector (antenna with lens) candidates suitable for a high-efficiency terahertz wave collector array.
FY 1998	Design and begin to fabricate the detector/collector array; Begin development of the terahertz wave source (illuminator) that will provide sufficient reflected power for imaging.
FY 1999	Complete the fabrication of the detector/collector array and test their interface; Design, construct and test quasi-optical imaging optics; Start development of pixel array-to-electronics interface.
FY 2000	Complete development of source and start assembly of system.
FY 2001	Complete assembly of system and perform testing.

Waveform Synthesis and Impedance Metrology

(New project combined from former projects "Impedance Standards and Measurement Techniques" and "Generation and Measurement of Precise Signals")

Project Leader: Nile M. Oldham

Staff: 4.0 Professionals, 2.0 Technicians

Funding level: \$0.9 M

Funding sources: NIST (50%), Other Government Agencies (30%), Other (20%)

Objective: Provide calibrations and special tests and develop new measurement capability to support the basic quantities of voltage, current, phase angle, power/energy, ratio, and impedance using waveform synthesis and sampling techniques as well as classical electrical measurement methods spanning a frequency range of dc to 100 megahertz.

Background: Industrial, university, and government laboratories have calibration requirements for basic instrumentation standards to support calibrators, digital multimeters (DMMs), impedance (LCR) meters, and phase meters. With multifunction/multirange capability, wide frequency ranges, and sophisticated self-calibration features, the ability to provide a comprehensive coverage of the calibration quantities for these instruments, at desired accuracies and ratios, is increasingly challenging. The market for these instruments is over \$500 million annually. Similarly, the power industry legally requires NIST traceability to equitably distribute over \$200 billion of electric energy generated annually. High-accuracy power measurements are required to determine the efficiency of electric equipment during development and manufacture, and for quality control. Power and energy measurements have been complicated by an increasing proportion of nonlinear loads and alternate energy generators, which produce nonsinusoidal waveforms with frequency components in excess of 100 kilohertz. In response to the above needs, new waveform generation and measurement capability at NIST will be developed to support the basic quantities of voltage, current, phase angle, ratio, and impedance, using techniques for generating and measuring voltage and current waveforms over the frequency range up to 100 megahertz. Specific goals include: (1) developing techniques to measure generalized impedances at signal frequencies up to 1 megahertz; (2) developing automated measurement systems capable of providing near state-of-the-art traceability for voltage, current, resistance, and phase angle in the frequency range from dc to 30 megahertz; and (3) developing new 60 Hz power/energy standards and extending the frequency range of power measurements up to 400 kilohertz.

Current Tasks:

1. Voltage and current

FY 1987	Began development on a new alternating voltage standard and a wideband transconductance amplifier.
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FY 1988	Presented papers describing a digitally synthesized source (DSS) and a transconductance amplifier; Began trial calibration service for digital multimeters (DMMs).
FY 1989	Completed a DSS to generate signals at frequencies up to 50 kilohertz with calculable voltage output and a transconductance amplifier with an output current of 20 A and maximum operating frequency of 100 kilohertz.
FY 1990	Developed a technique to measure low voltages (2 mV - 200 mV) at frequencies up to 1 megahertz with a factor of 10 improvement in uncertainty; Patents issued on the DSS and the transconductance amplifier and licensed both to a commercial instrument manufacturer.
FY 1991	Completed initial development of the multifunction calibration system (MCS) and offered Special Tests for DMMs (all functions); Demonstrated the DSS as a calculable current source.
FY 1992	Completed two measurement assurance programs for ac voltage using the DSS.
FY 1993	Completed a new version of the DSS controlled using a standard computer interface with an output current of 100 amperes and delivered 15 copies to sponsor (Sandia National Laboratories - SNL).
FY 1994	Announced a 25-point multifunction Special Test for DMMs with one-week turn-around time.
FY 1995	Completed development of a new transconductance amplifier with an output current of 100 amperes; Offered new 230-point test for DMMs used to provide state-of-the-art traceability for multifunction calibrators.
FY 1996	Extended the range and characterized the MCS for the calibration of currents up to 10 amperes; Developed a model to describe the low frequency performance of thermal voltage converters; Developed a scheme to reduce low voltage measurement uncertainties due to complex loading errors; Began organizing an international comparison of electrical units (with North, South, and Central America) using DMMs as transportable standards.
FY 1997	Train participants and begin the interamerican international comparison using DMMs; Complete documentation for the MCS and offer extended calibration services.
FY 1998	Develop a Special Test service for DMMs used by NIST's voluntary laboratory accreditation program to audit basic electrical units (voltage, current, and resistance).
2.	Impedance
FY 1990	Designed a new dual-channel, digitally synthesized source as a first step in modernizing low-frequency ratio and impedance bridges in the Division.
FY 1991	Demonstrated a digital impedance bridge (DIB) using a dual-channel, digitally synthesized source; Developed a programmable 30-bit binary inductive voltage divider (BIVD); Completed an inductance comparison with the Canadian national laboratory.
FY 1992	Incorporated the BIVD into an automatic bridge to measure the linearity of precision commercial inductive voltage dividers.
FY 1993	Constructed and tested a sampling probe for the DIB to measure standard inductors; Established a procedure to use a commercial impedance meter to replace the manual Type 12 capacitance bridge; Used the BIVD bridge to evaluate a temperature bridge for use in a NASA Space Shuttle experiment.

FY 1994	Completed and documented the sampling probe for the DIB; Completed an international comparison of inductance (10 mH); Described a new error decomposition method for characterizing inductive voltage dividers based on modeling techniques; Developed software to improve inductance measurements by using predicted values based on a regression of previous test results.
FY 1995	Completed an analysis of uncertainties of capacitance calibrations; Developed a VXIbus-based impedance synthesizer and used it to test bioelectrical impedance analyzers for sponsor (National Institutes of Health); Began using a commercial capacitance meter for the calibration of capacitors; Evaluated a new commercial fused silica capacitor.
FY 1996	Completed the impedance calibrator; Demonstrated a multirange 3-voltmeter probe to measure inductors; Demonstrated a modeling-based system for characterizing 4-terminal pair capacitors.
FY 1997	Complete a prototype system for characterizing 4-terminal pair capacitors at frequencies up to 1 megahertz; Complete the 3-voltmeter probe and begin using it to calibrate inductors; Document the capacitance calibration services.
FY 1998	Offer special tests for dissipation factor up to 1 megahertz; provide special tests for inductors up to 100 kilohertz; Begin using the automatic binary inductive divider system to perform special tests; Replace the Type 2 capacitance bridge.
FY 1999	Develop a general-purpose impedance bridge which employs a waveform generator and equivalent-time sampling probes; Document the new impedance calibration services; Offer special tests for LCR meters.
3.	Phase
FY 1988	Initiated a calibration service for digital phase meters for signals with frequencies between 1 hertz and 50 kilohertz.
FY 1990	Developed a dynamic test method for high frequency phase meters to support laser interferometry.
FY 1991	Completed development of a phase standard for signals between 1 and 20 megahertz and identified the phase meters in commercial interferometers as major source of error; Developed a state-of-the-art sampling phase meter and offered a Special Test for phase generators which produce signals at frequencies up to 100 kilohertz.
FY 1992	Developed new signal processing algorithms for the NIST sampling phase meter; Developed a self-calibration technique to characterize phase meters and generators out to 20 megahertz.
FY 1993	Developed a VXIbus-based system for calibrating phase meters and generators.
FY 1994	Simulated a phase measuring system for measuring very-high-frequency omni-directional ranging (VOR) phase meters for aircraft navigation system now expected to be in use beyond 2000.
FY 1995	Developed a VXIbus-based test set for VOR phase meters.
FY 1996	Tested and delivered a VXIbus-based system for testing the phase meters in VOR receivers to the Army.
FY 1997	Offer a Special Test service for VOR phase meters.
FY 1998	Upgrade and document the NIST phase angle calibration facility and offer extended calibration services.

4. Power and energy

FY 1988	Completed two new calibrators for the power/energy calibration facility, based on digitally synthesized generators; Began development of an audio-frequency current-comparator-based power bridge.
FY 1989	Participated in an international comparison of audio-frequency power (NIST only participating national lab with capability to measure power at signal frequencies above 5 kilohertz); Began development of a prototype power-frequency sampling wattmeter.
FY 1990	Completed the NIST audio-frequency power bridge.
FY 1992	Completed the prototype power-frequency sampling wattmeter.
FY 1993	Investigated the possibility of using a miniature current-comparator-based power bridge as an ultra-stable transport standard for international comparisons.
FY 1994	Demonstrated a power measurement at a signal frequency of 200 kilohertz to support wideband commercial wattmeters and power system analyzers.
FY 1995	Began the planning stage of a NIST-sponsored international comparison of 50/60 hertz power.
FY 1996	Completed the first stage of the international comparison (with the national measurement laboratories of Canada and Germany); Demonstrated a 3-voltmeter technique for measuring wideband power at frequencies up to 500 kilohertz; Assumed chair of ANSI Committee on Electricity Metering (C-12).
FY 1997	Develop new 50 hertz - 400 hertz power measurement system; Complete half of the 50/60 hertz international comparison.
FY 1998	Complete 50 hertz - 400 hertz power measurement system; Report on the international comparison of 50/60 hertz power.
FY 1999	Document power measurement capabilities at frequencies up to 500 kilohertz and offer extended calibration services.

Measurements for Complex Electronic Systems

Project Leader: T. Michael Souders

Staff: 2.0 Professionals, 0.2 Guest Scientist, 0.1 Technician

Funding level: \$0.5 M

Funding sources: NIST (51%), Other Government Agencies (49%)

Objective: Develop improved methods and techniques for optimum testing scenarios by: (1) developing improved mathematical models and test procedures, especially for self-calibrating systems; (2) estimating the confidence and test coverage in a given calibration or test procedure; and (3) developing a Testing Strategies Software Toolbox.

Background: For both manufacturers and users, the testing and calibration costs of complex electronic devices and instrumentation have become a dominant factor in total life-cycle costs. For example, typical test costs for mixed-signal integrated circuits range from 20% to 50% of the sale price. Similarly, in the acceptance and field maintenance of electronic equipment, the costs of testing can equal or exceed the initial purchase price. Confidence levels, test coverage, and test and calibration procedures are often inadequate to assure the extremely low defect levels and tight performance tolerances that are now required. This is a generic problem throughout the spectrum of electronic products. It has been shown that the testing strategies developed at NIST can have a substantial impact on the production costs. These cases have been made for both analog and mixed-signal products, such as data converters and multirange measurement instruments. However, the problem of effectively disseminating this technology remains. Specific goals include: (1) developing a software toolbox for test engineers that relieves the burden of complex mathematical software development; (2) Providing tutorial background documentation of the NIST testing strategies approach; (3) Developing and conducting workshops on the use of the approach and software toolbox; and (4) applying the approach to new testing problems or device types.

Current Tasks:

1. Testing strategies

FY 1989	Evaluated limitations of linear models, and developed a capability for modeling second order time-domain sensitivities; Published papers on "Time-Domain Testing Strategies and Fault Diagnosis for Analog Systems" and "Ambiguity Groups and Testability".
FY 1990	Successfully applied NIST-developed testing strategies to a population of 128 commercial 13-bit analog to digital converters; Achieved 0.03 least-significant-bit (rms) uncertainty in linearity estimates at all 8192 codes using 64 measurements; Presented paper on method and results.
FY 1991	Conducted the first NIST testing strategies workshop; Two integrated circuits manufacturers began using NIST method in production testing; A testing

	company announced software product based on NIST work; Published tutorial paper in IEEE's <i>Spectrum</i> and paper on analog to digital converter application in a conference proceedings.
FY 1992	Developed an accurate error model for multifunction instrument and demonstrated effective test results with 80% reduction in test cost; Began analysis of theoretical performance limits of empirical models.
FY 1993	Prepared two papers on modeling and test point selection for a commercial thermal transfer standard; Conducted second testing strategies workshop.
FY 1994	Established theoretical basis for, and proof of, maximum likelihood properties of empirically derived error models; Developed expressions for statistical confidence intervals for results obtained from linear models; Began development of Testing Strategies Toolbox; Conducted third testing strategies workshop.
FY 1995	Completed work on procedures to estimate the effects of nonmodel errors and to compute prediction intervals that account for them; Demonstrated application of nonmodel error analysis to two instruments and began applying the approach to a NIST calibration service (with estimated savings to customers of \$26k per test); Completed subroutines and user interface for NIST Testing Strategies Toolbox; Demonstrated prototype; Developed and demonstrated an empirical model and efficient test plan for a multifunction calibrator.
FY 1996	Completed 2/3 of NIST Testing Strategies Toolbox tutorial guide (mathematical background) and 1/2 of user's manual (in browsable hypertext), and released version 1.0; Completed analysis and issued first test report based on NIST Empirical Linear Prediction approach and presented paper on results.
FY 1997	Prepare and conduct fourth workshop and training program (for DoD sponsors); Complete Toolbox tutorial guide and user's manual, and complete and release version 2.0 of toolbox; Develop a plan for an adaptive modeling approach in which calibration history is used to iteratively reduce subsequent calibration costs; Demonstrate NIST approach on new device type or architecture.
FY 1998	Document NIST testing strategies methods for analog and mixed-signal devices.
2. Device/system analysis	
FY 1992	Began feasibility study of new, hardware-efficient, on-line error detection approach for analog systems.
FY 1993	Completed study of on-line error detection scheme and documented results.
FY 1994	Assisted Office of Law Enforcement Standards in development of integrated services digital network (ISDN) telecommunications equipment.
FY 1995	Developed approach for analyzing self-calibrating systems and applied to a self-calibrating instrument; Began development of ISDN standard for state and local law enforcement agencies.
FY 1996	Continued development of the ISDN standard.
FY 1997	Complete and disseminate the ISDN standard.